Institute for Soldier Nanotechnologies

John D. Joannopoulos
Director, Institute for Soldier Nanotechnologies
Francis Wright Davis Professor of Physics
Massachusetts Institute of Technology

Selected Research Highlights & Potential Impact for Army Applications

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Massachusetts
Institute of
Technology

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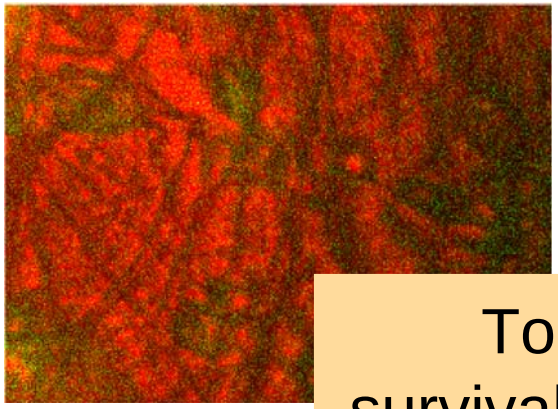
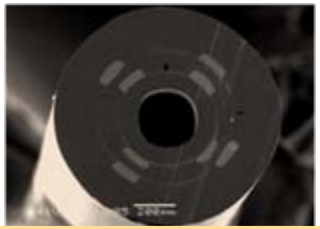
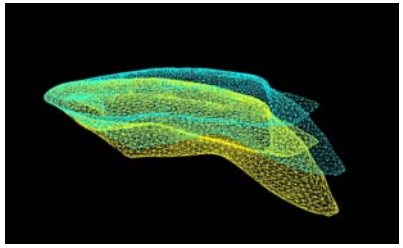
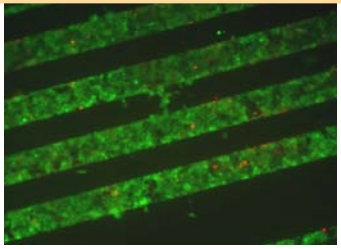
Mission & Goals

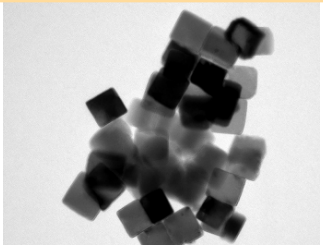


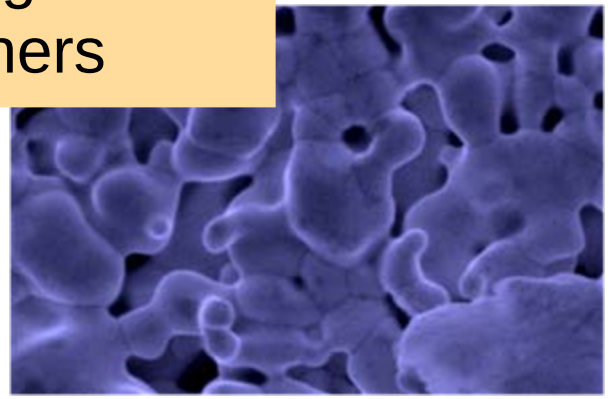


To dramatically improve the survivability of the Soldier by working and extending the frontiers of Nanotechnology *through fundamental research …* and transitioning with our Army & Industry Partners









What is Nanotechnology?

Properties of materials (e.g. electronic, photonic, mechanical, magnetic) become **size dependent** below a critical length scale of ~ 500 nanometers.

(The diameter of a human hair is about 80,000 nanometers)

Opportunities:

- **New** materials**, new** phenomena**, new** properties **unattainable** in nature

A Three-Member Team

ISN Dedicated Facility

State of the art instrumentation

47	Faculty (10 Departments)
80	Grad students
30	Post-docs
2	Uniformed Army Scientists
3	Civilian Army Scientists
2	Industry Scientists
1	USN/MC TTS
1	Uniformed Army Liaison

Industry Consortium

Battelle, CIMIT, Dow Corning, DuPont, Foster-Miller (A QinetiQ Company), GORE (Creative Technologies Worldwide), Honeywell, ICX nomadics, JEOL USA, MSA, nano-c, Northrop Grumman, Raytheon, tsi

Army Sci & Tech Labs

ARL, US Army Natick Soldier RD&E Center, Armament Research, Development & Engineering Center (Picatinny NJ), Edgewood Chemical Biological Center, Walter Reed Army Medical Center

Potential Impact for Army App's

1 – Low-cost, room-temperature night-vision and communications in the infrared (IR) for increased Soldier situational awareness

2 – Autonomous and self-administered medical care for faster, more extensive, far-forward medical treatments

3 – Lightweight, flexible & breathable structural materials for *comfortable* blast & ballistic protection

4 – Flexible, lightweight nano-coatings for multiple survivability capabilities
e.g., against moisture, bacteria, spores, hazmats, fire, EMI …

5 – Multi-functional *full-body* battlesuit to enhance the Soldier's senses of light, heat, and sound

6 – Ultra-sensitive explosives sensors for accurate hand-held, robot-integrated, and stand-off IED detection

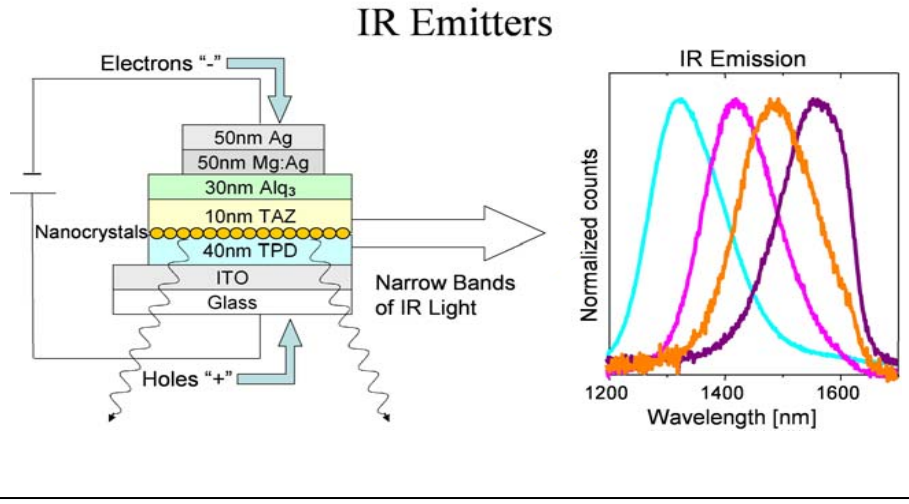
Supporting FOC's: Battlespace Awareness, Battle Command, Human Dimension, Maneuver Support, Maneuver Sustainment, Protection

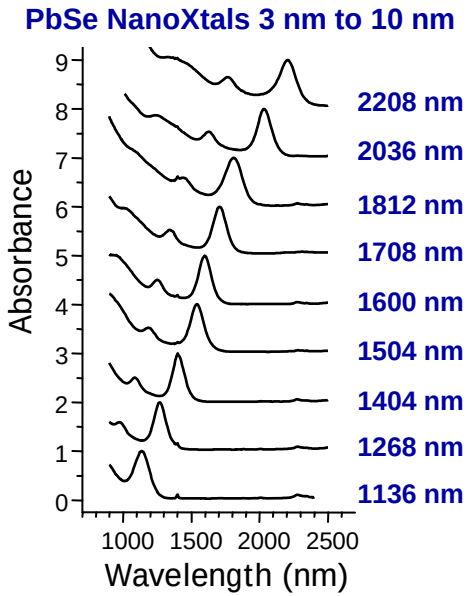
Accomplishments & Opportunities - 1

Nanoparticle systems as low-cost room-T devices for IR sensing & comms:

Enhance situational awareness in the battlespace

Band-Gap Engineered Nanocrystals (aka QDs)
& Low-Cost Polymer Processing





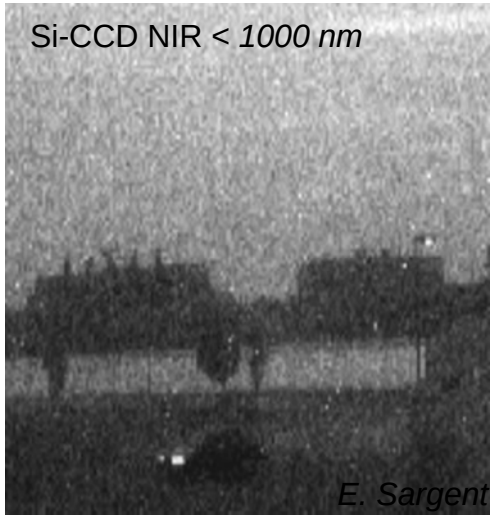
- Develop low-cost QD-based optoelectronic devices in the visible & IR

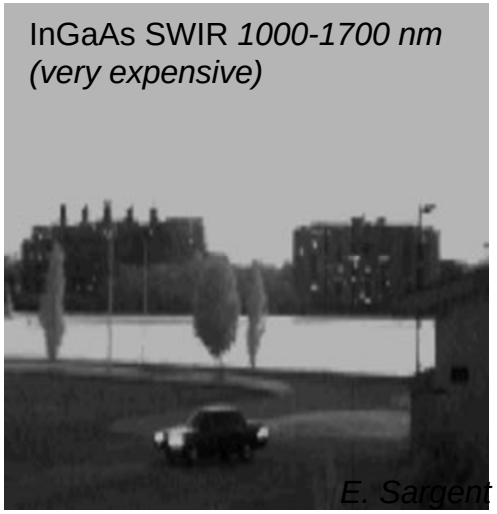
Accomplishments & Opportunities - 1

Nanoparticle systems as low-cost room-T devices for IR sensing & comms:

Enhance situational awareness in the battlespace

Hydroxyl nightglow dominates ~ *1000 - 2300 nm*





- Develop low-cost QD-based optoelectronic devices in the visible & IR

Accomplishments & Opportunities - 1

Development of IR imager based on solution synthesized colloidal nanocrystal quantum dots

M. Bawendi
V. Bulovic
M. Kastner
S. Geyer

Nanocrystal Synthesis

Photodector Fabrication

Electro-Optic Response

SEDD
P. S. Wijewarnasuriya
V. J. Nathan

NVSED
R. Littleton

Raytheon
F. B. Jaworski

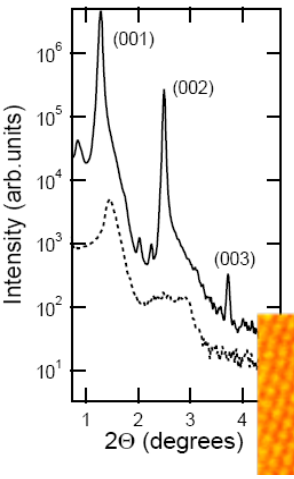
Focal Plane Array Design

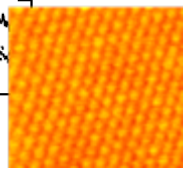
Read Out Electronics

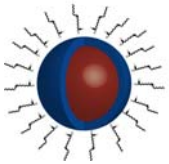
Figures of Merit Determination

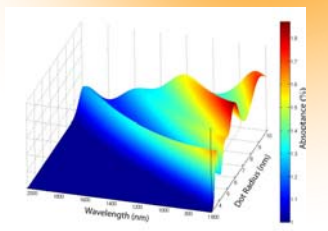
Test Device & Focal Plane Arrays

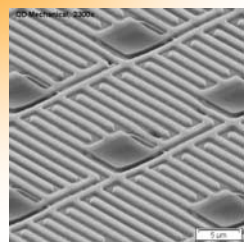
Nanocrystal Based IR Imager

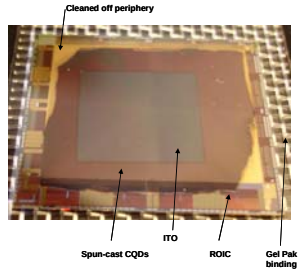












Accomplishments & Opportunities - 2

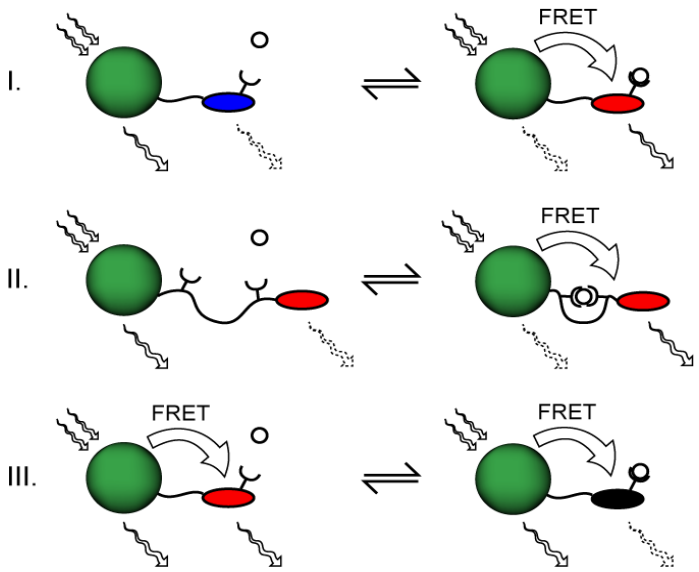
Novel QD(nanoparticle)/Dye Constructs as Environmental Reporters for Medical Diagnostics & Toxin Sensing

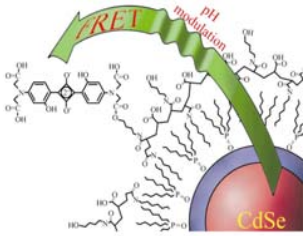
M. Bawendi
D. Nocera

Ratiometric, quantitative FRET between QD & sensing dye molecules: measure pH, blood O_2 & glucose, or detect hazardous substances

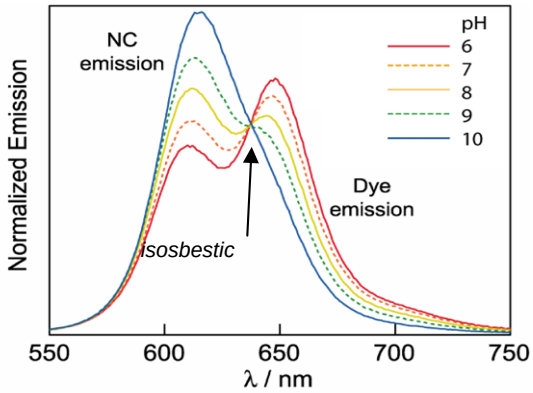
ERDC/CERL
A. Kumar

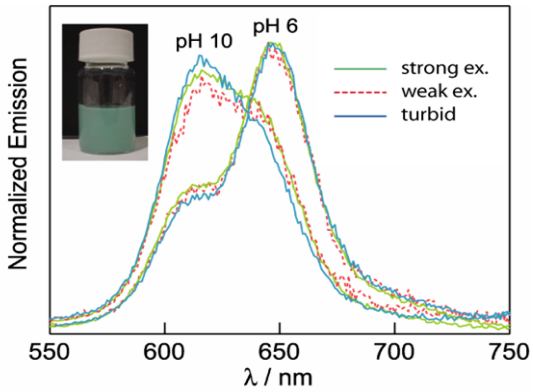
Reversible sensing modalities





CdSe QD core linked to pH sensitive squaraine dye



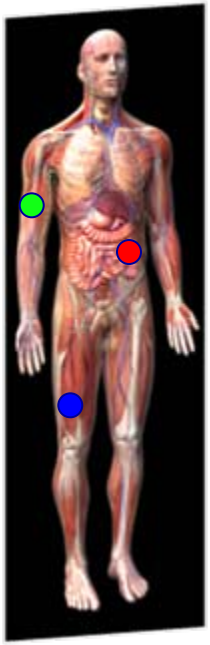


Accomplishments & Opportunities - 2

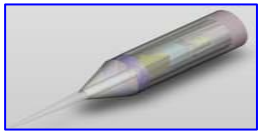
Development of autonomous & self-injected drug delivery with wearable & implantable MEMS-based devices in the battle space:

M. Cima
N. Elman

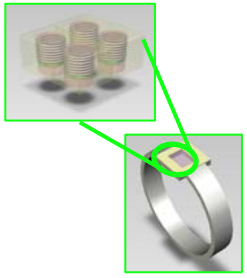
Develop Rapid Reconstitution Packages (RRP's) to improve drug instability & deployment logistics: e.g. use for hemorrhagic shock, TBI,chem/bio agents



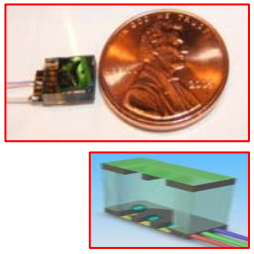
Auto-injection (RRP) for trauma

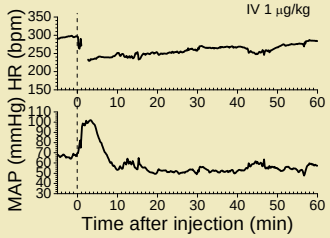


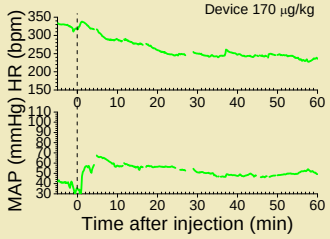
Wearable (RRP) for auto/remote actuation

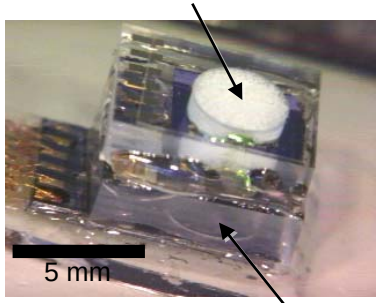


Implantable SubQ device









Rapid Reconstitution of Atropine

Accomplishments & Opportunities - 3

Development of ceramic nanoparticle-reinforced novel architectures for potential flexible, lighter-weight & stronger armor

N. Thomas
M. Boyce
S. Kooi

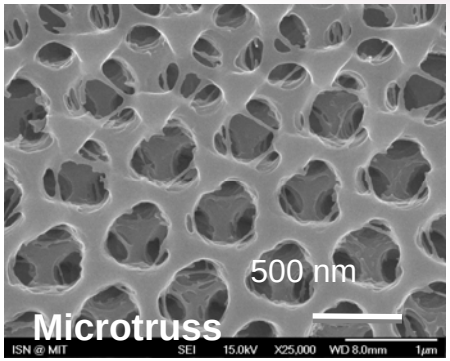
Picatinny Arsenal
D. Kapoor

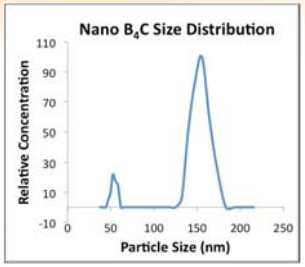
Photoresist & Lithography → **3D Microtruss Templates**

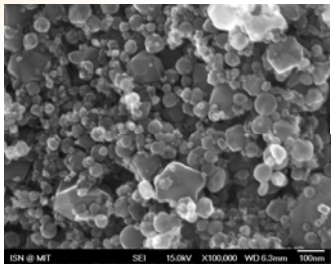
Ceramic Precursor + **Ceramic Nanoparticles** → **Mixture**

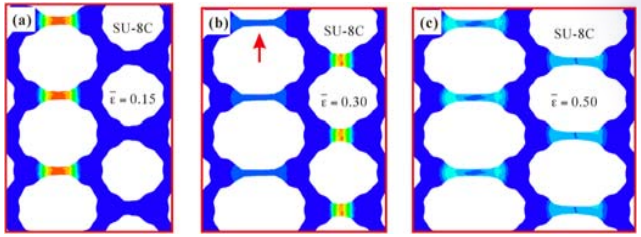
boron carbide
silicon nitride
silicon carbide

Nanoparticle Infiltration → **Cured thermoset** → **3D Ceramic Nanoparticle Composites**

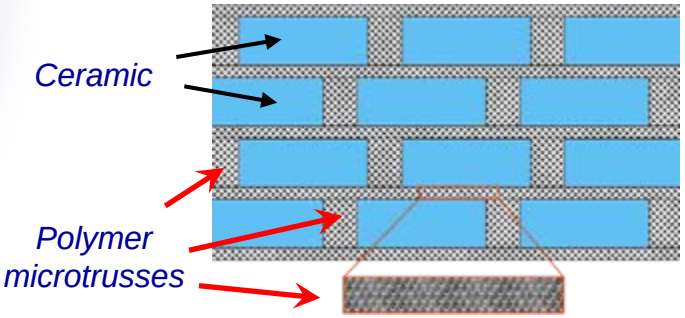








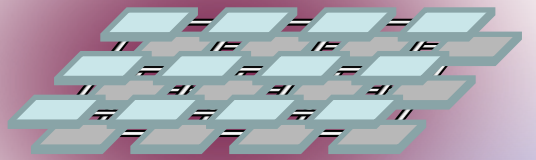
Bio-inspired Layered Composites



Accomplishments & Opportunities - 3

Enable the first CNT/graphene-linked flexible "Chain Maille" structures using precision placement of anisotropic nanostructures

M. Strano



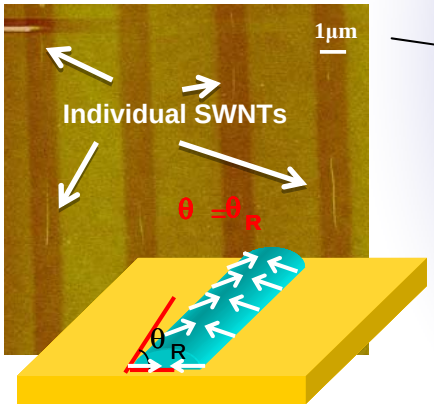
π- π Stacking of Alternating Chain Maille Layers

US Army Corps of Engineers®

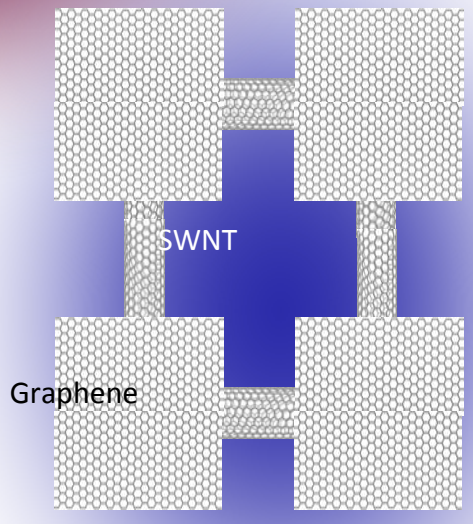
CERL/ITL
C. Marsh
C.R. Welch

Atomistic Modeling & Mechanical Testing

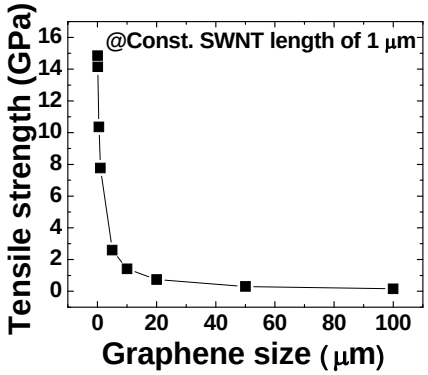
Micro-hydrodynamic Placement Allows Massively Parallel Alignment/Placement



center-line deposition



Pattern Chain Maille Networks of Carbon Nano-materials



WMRD
A.J. Hsieh

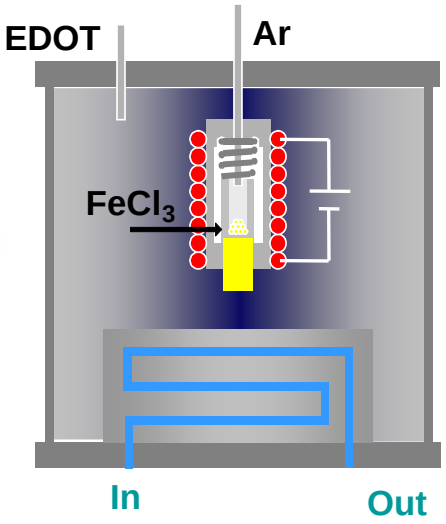
Accomplishments & Opportunities - 4

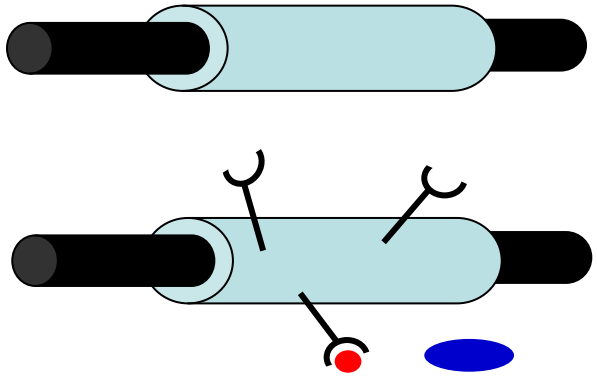
Karen Gleason et al.

Gentle Chemical Vapor Deposition (CVD) methods for enabling multi-functional polymer coatings of fibrous & hard surfaces:

CVD processing for both insulating & conducting polymers!

oCVD for conducting polymers





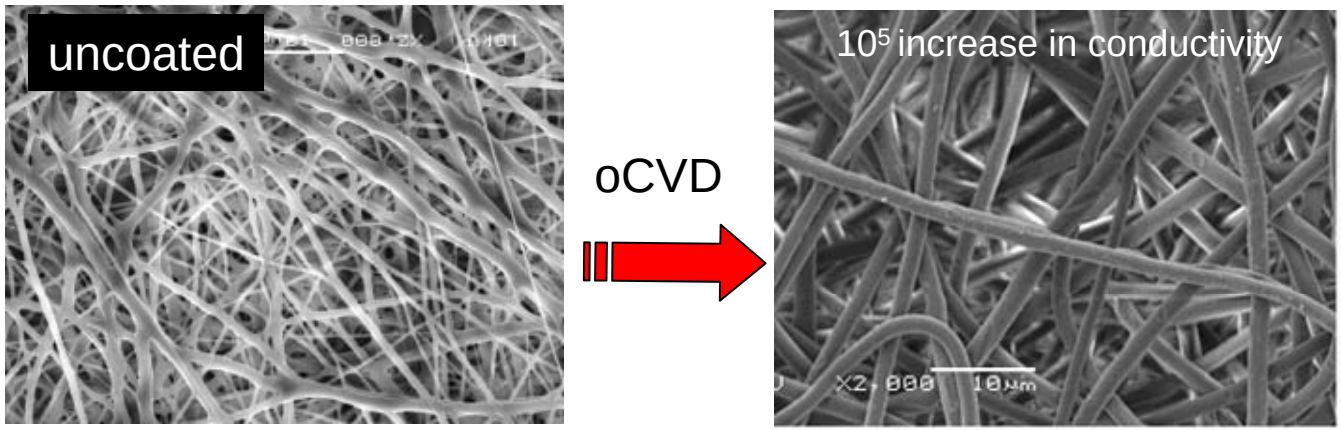
Conformal coverage!

Accomplishments & Opportunities - 4

Karen Gleason et al.

Gentle Chemical Vapor Deposition (CVD) methods for enabling multi-functional polymer coatings of fibrous & hard surfaces:

CVD processing for both insulating & conducting polymers!



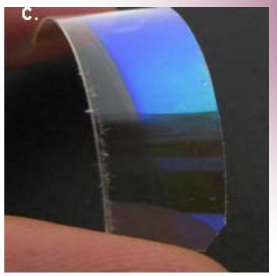
with K. Senecal **: develop resistivity-based sensor for pathogens**

- Develop for a broad-range of sensing and protective coatings (toxic agents, water-repellency, fire-retardency, EMI-shielding, etc ..) for the battle-suit and face shields

Accomplishments & Opportunities - 4

Flexible dielectric Bragg reflectors (DBRs) for laser eye protection

K. Gleason



Room-T deposition of flexible polymer layers sandwiching thin inorganic layers

Flexible DBR Prototype

iCVD Processing

Adhesion Testing

Mechanical Testing

Stack Structure Design

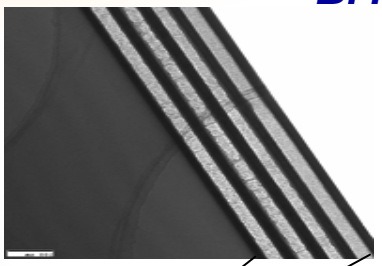
Optical Characterization

Scale-up

John Lock
(ISN Alum)
Norm Rice
Pete Schuler

WMRD
A. Rawlett

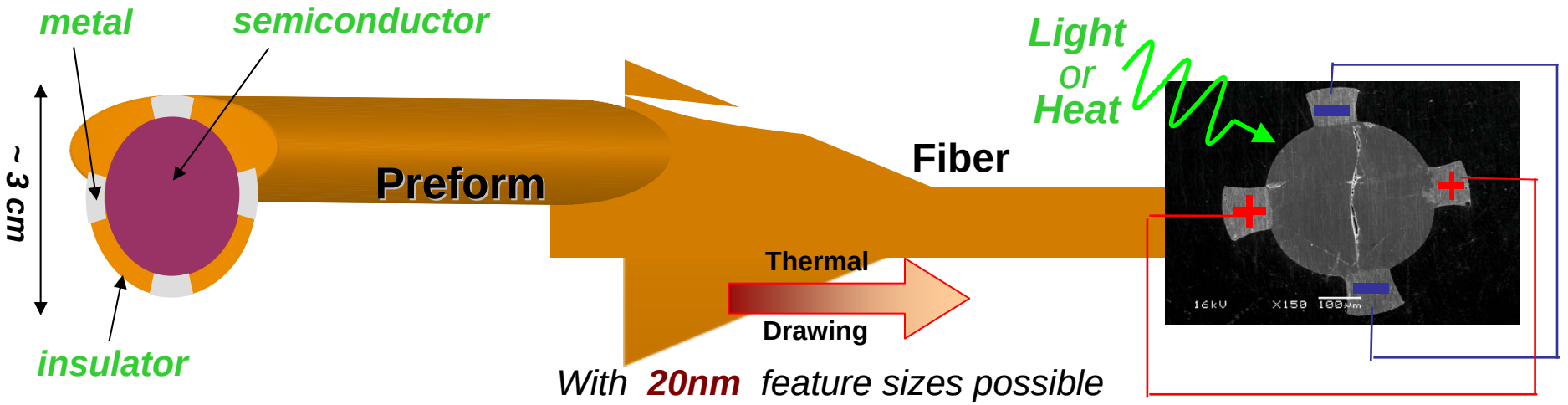
NSRDEC
B. Kimball



Accomplishments & Opportunities - 5

Towards novel optoelectronic fiber-devices:

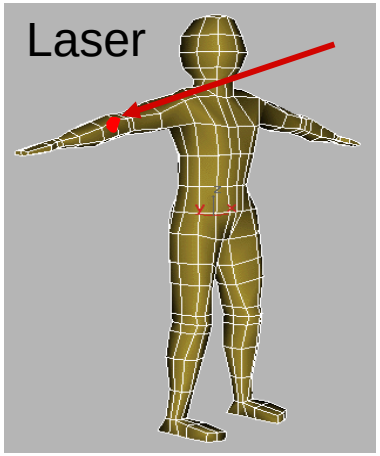
Full-body sensing – new paradigm fibers & fabrics that can see, feel, hear…



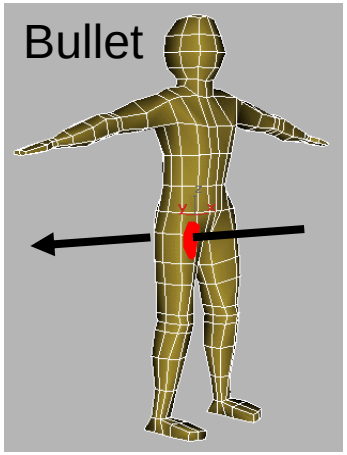
Full Body Combat ID;

Laser-to-Uniform Non-RF Communications;

Improved MILES



Full Body Thermal Sensing *Remote Combat Triage*

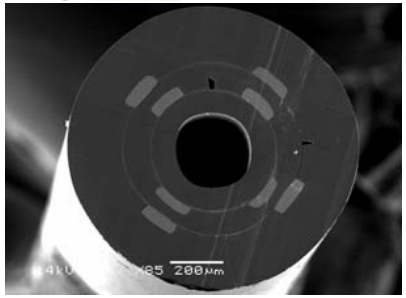


Accomplishments & Opportunities - 5

Design, fabricate, and implement an optoelectronic fiber-device covering for combat ID and line-of-sight IR communication

Y. Fink
J. Joannopoulos
MAJ R. Blair

NSRDEC
R. Elder
R. Masadi
K. Shukla
A. Taylor



Optoelectronic Fiber-Device

Preform Fab

Specs

PEQ-2

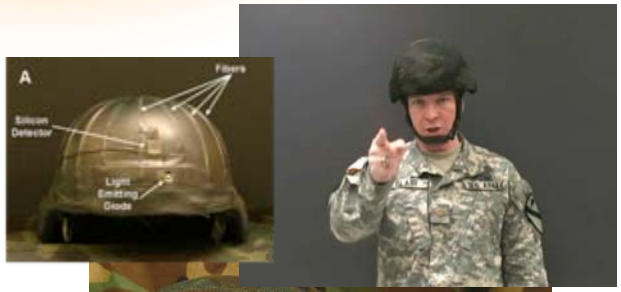
Fiber Drawing

Soldier Helmet

Fiber Device

ID & IR Comm's

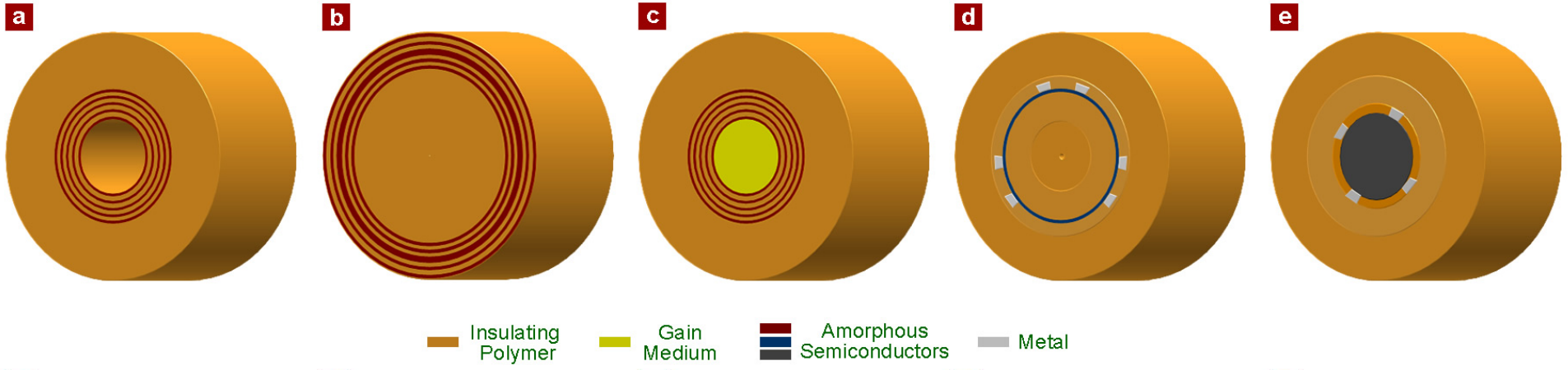
Characterization of ICOM-H



ID & Comms Multifunctional Helmet


BLAIR
U.S. ARMY

Multimaterial Fiber Devices



Hollow transmission fibers	Optical cavity fibers	Surface emitting fiber lasers	Thermal detector fibers	Optical detector fibers

- Transition to civilian medical community: Fibers for novel CO_2 laser endoscopic surgery
  - Fibers for acoustic detection, photovoltaic & thermoelectric (cooling) applications
  - Fibers for improved FIDO sensing element

Accomplishments & Opportunities - 6

Development of *Amplifying Fluorescent Polymers* for high-sensitivity detection of chemicals:

Ultra-sensitive IED detection in theater and … US ports of entry

Championed by HQDA

Transportation Security Administration

"TSA ... announced operational pilot testing … of a technology capable of screening sealed bottled liquids… Fido PaxPoint ."

- Develop AFP's for broad range of explosives

Accomplishments & Opportunities - 6

Versatile lightweight small form-factor ISN-fiber explosives sensors with *high-sensitivity*, *multi-analyte* and "*stand-off*" detection capabilities

Y. Fink
J. Joannopoulos
O. Shapira

L. Takiff
A. Rose

Fiber Design & Preform Fab

Detector Modalities (AFP & IFP) & Specs

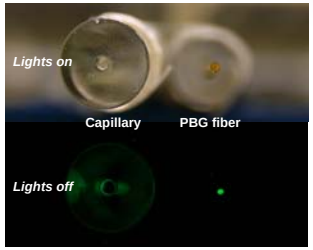
Fiber Drawing

Characterization & Testing

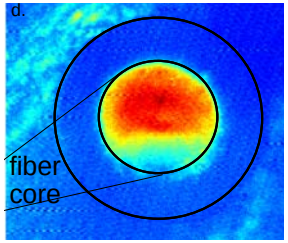
Optimization of Performance

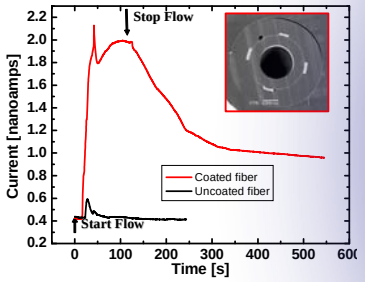
Scaling to Multiple Analyte Detection

Next Generation Detectors

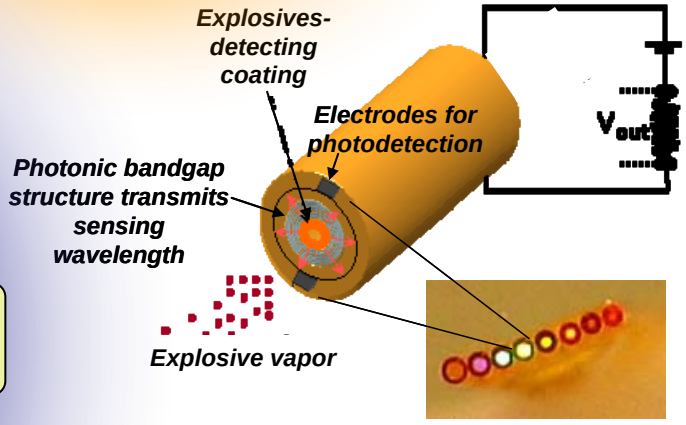


PBG fiber provides 15-fold signal enhancement





SIMM fiber upon exposure to liquid explosive vapor



SIMM fibers for explosives detection: upon exposure to solid or liquid explosive vapors, the fiber converts light emission at the core to an electrical signal. Each fiber in bundle can be designed sensitive to a different type of explosive

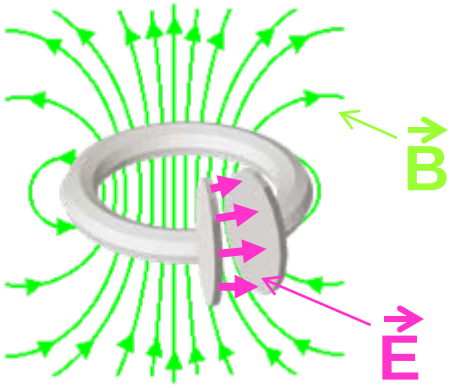
Wireless Nonradiative Power Transfer

Soljacic, Joannopoulos, Fisher et al.

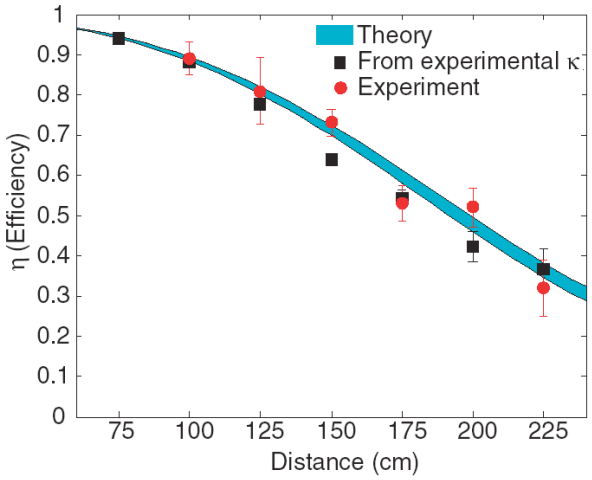
Resonant cavities in photonic crystal nanostructures can be tuned to almost "any" desired frequency, "any" evanescent tail extent, and can exhibit magnetic resonant behavior even in a purely dielectric material

As a first step & simple proof of principle: explore energy transfer through evanescent-tails of simple self-resonant magnetic coils:

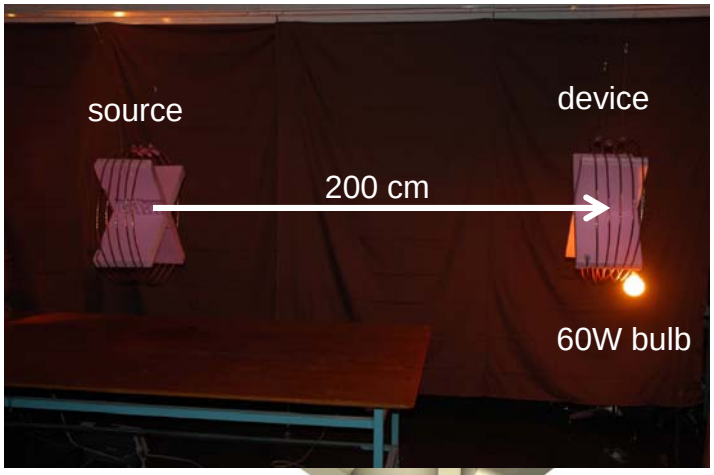
***Exploit "strong coupling" regime:* coupling strength » loss rate for *efficient* energy transfer**



Magnetic Resonance



SCIENCE, ***317****, 83 (2007)*



Summary

Nanotechnology-Enabled Enhanced Survivability for the Soldier by Exploiting:

- ***Synergistic MIT, Army, Industry Partnership***
- ***Innovative Cutting-edge 6.1 Research Portfolio to Help Identify "Revolutionary" Opportunities***

Accomplishments & Opportunities - 3

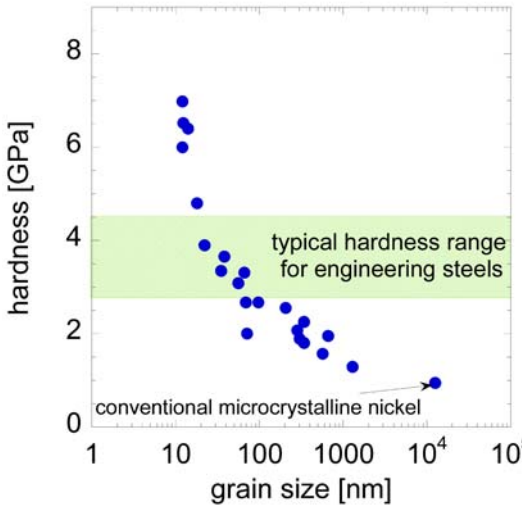
Develop flexible nanoparticle metal-alloy fibers that combine high strength with toughness to resist impact and blast:

Exploit unique deformation mechanisms at the nano-scale that can operate at high strength levels and dissipate significant energy without fracture

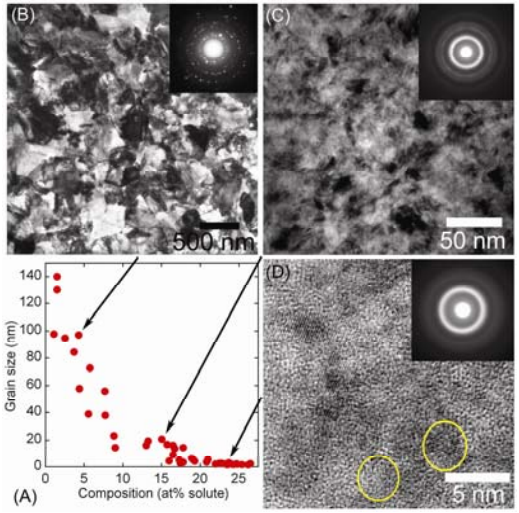
C. Schuh
N. Marzari
R. Radovitzky

BUT… nanocrystalline metals are thermodynamically unstable due to high volume fraction of grain boundaries

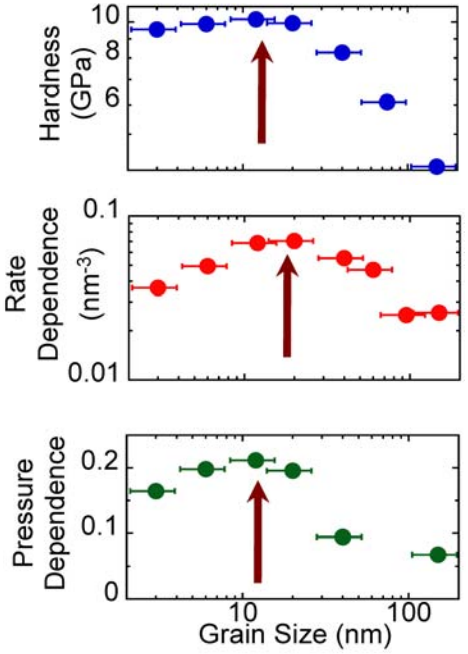
D. Kapoor



Strength increased with strain-rate
Strength increased with pressure



Demonstration of stable Ni nanoparticles in a Ni-W alloy



Accomplishments & Opportunities - 4

Development of resistivity-based sensors for pathogens

K. Gleason

NSRDEC
K. Senecal

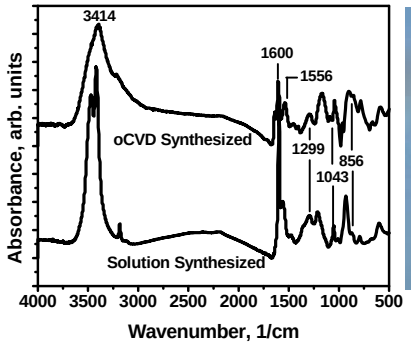
Conducting Monomers → **oCVD Processing**

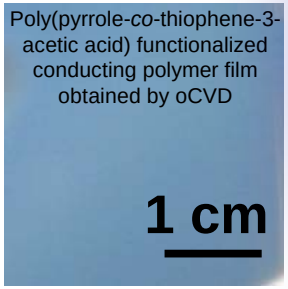
Conducting Polymer + **Polymer Functionalization** → **Fiber Mat Selection**

oCVD Processing + **Fiber Mat Selection** → **Fiber Mat Coating**

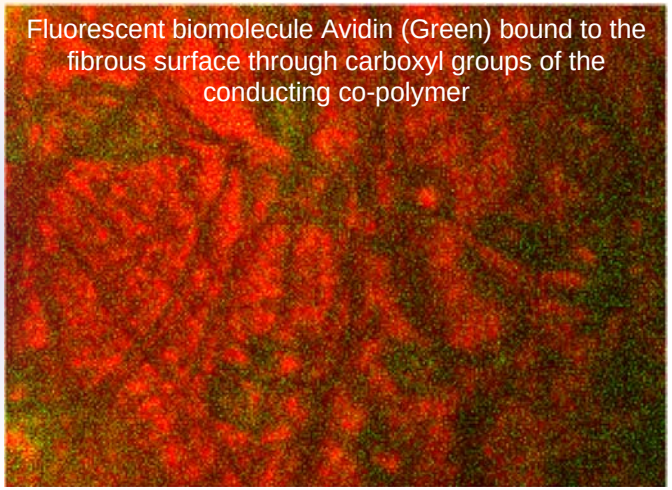
Fiber Mat Coating → **Characterization** → **Pathogen Sensor**

oCVD PEDOT conformal coating





Excellent uniformity !



Optical micrograph of cond. polymer coated fiber mat

Accomplishments & Opportunities - 2

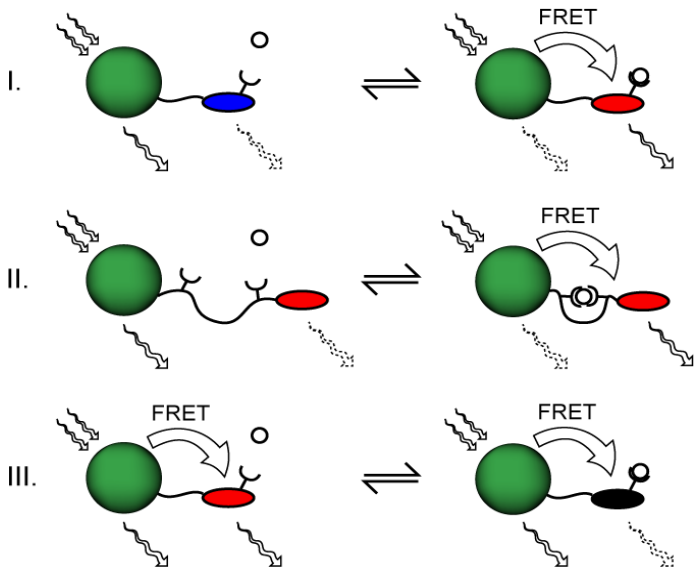
Novel QD(nanoparticle)/Dye Constructs as Environmental Reporters for Medical Diagnostics & Toxin Sensing

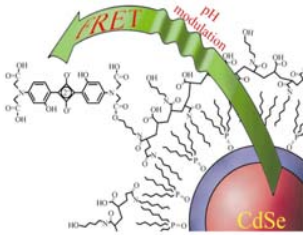
M. Bawendi
D. Nocera

Ratiometric, quantitative FRET between QD & sensing dye molecules: measure pH, blood O_2 & glucose, or detect hazardous substances

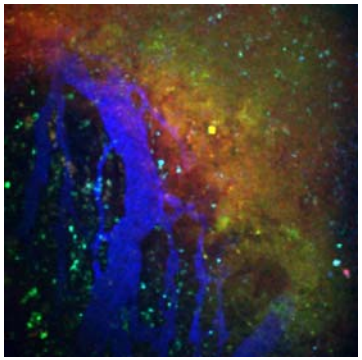
ERDC/CERL
A. Kumar

Reversible sensing modalities





CdSe QD core linked to pH sensitive squaraine dye



In vivo MPLSM of sensors (dye & QD emission) in murine tumor